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ABSTRACT

Traditional methods for task analysis have been largely based on the Instructional Systems Development (ISD) model, which is widely used throughout industry and the military. The first part of this document gives an overview of cognitive task analysis, which is conducted within the first phase of ISD. The following steps of cognitive task analysis are outlined: (1) identification of key job tasks and training issues; (2) visual representation of the knowledge structure; (3) description of cognitive processes underlying performance; (4) identification of differences between experts and less-experienced personnel; and (5) implications of results for the design phase. Following this overview, the paper presents, in outline form, guidelines that describe the procedures and deliverables for a cognitive task analysis. The deliverables (research proposal, interim report, and final report) are described, and the information contained in them is outlined. Guidelines for conducting a cognitive task analysis are presented in the following steps: establishing analytic goals, selecting subjects, selecting data collection methods, analyzing data, validating results, communicating and interpreting results, and formulating training recommendations. Attachments include two figures that provide examples of network scaling and an example of an expert mental model. (YLB)

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A STANDARD PROCEDURE FOR CONDUCTING COGNITIVE TASK ANALYSIS

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Abstract

Traditional methods for task analysis have been based largely on the Instructional Systems Development (ISD) model, which is widely used throughout industry and the military. The ISD model includes five phases: (Task) Analyze, Design, Develop, Implement, and Control. Current ISD analysis methods have proven effective for analysis and training of psychomotor skills, but offer little insight into jobs involving complex cognitive skills, which increasingly require training today.

Cognitive methods have been used to conduct task analyses to support training development, particularly where the job to be trained involves complex cognitive skills requiring decision-making, problem-solving, attention-switching, and/or the effective organization and retrieval of vast amounts of knowledge. Cognitive task analysis examines the cognitive processes and structures that support skilled work performance, and identifies important differences between experts as compared with those having less expertise.

Cognitive methods need to be incorporated into ISD task analysis. To date, however, no standard procedure has been developed for planning or conducting a cognitive task analysis. This paper presents a standard operating procedure for conducting a cognitive task analysis within the existing ISD analysis framework. The step-by-step presentation describes planning and conducting cognitive task analysis as part of the ISD process. Steps involved in establishing analytic goals, selecting subjects, selecting data collection methods, analyzing data, validating results, communicating and interpreting results, and formulating training recommendations are outlined in laymen's terms.

OVERVIEW: CONDUCTING COGNITIVE TASK ANALYSIS

1. Purpose. This section provides an overview of cognitive task analysis conducted within the analysis phase of ISD. Cognitive task analysis determines the mental processes and skills required to perform a task at high proficiency levels and the changes that occur as the skills develop. Cognitive task analysis helps determine how a task is learned, how learning can be facilitated, and what cognitive processes underlie and support effective job performance. This information is then used in the design phase to determine the most effective manner of training employees to achieve high levels of proficiency in job performance.

2. Critical Actions. During the cognitive task analysis, the following actions take place:

    - Identification of key job tasks and training issues
        - Identify major analytic goals
        - Identify training issues or problems
        - Select tasks suitable for cognitive analysis
    - Visual representation of the knowledge structure
    - Description of cognitive processes underlying performance
        - Skills
        - Conceptual and procedural knowledge
        - Learning and performance strategies
    - Identification of differences between experts and less-experienced personnel
        - Differences in knowledge structures (Optional)
        - Differences in skills
        - Differences in conceptual and procedural knowledge
        - Differences in learning and performance strategies

2. Critical Actions. (Continued)

   - Implications of results for the design phase
     - Training structure
     - Training sequence
     - Selection of instructional setting, media, and strategies

3. Documentation. The cognitive task analysis includes production of the following deliverables:

   - Research Proposal
   - Interim Report (Optional)
   - Final Cognitive Task Analysis Report

   These deliverables are described on page 7 (Guidelines for Conducting Cognitive Task Analysis).

   The research proposal explains how the specifications are to be met, by presenting a design for the research. The optional interim report details the progress made toward meeting the specifications, and describes any proposed modifications to the research proposal. The final report presents the complete results from the implementation of the research proposal.

4. Discussion of Cognitive Task Analysis. Cognitive task analysis examines the cognitive structures and processes (e.g., problem-solving, decision-making, attention allocation, self-monitoring, performance strategies, and knowledge organization) underlying expert performance. Comparisons are made between experts and less-experienced personnel to identify effective job performance skills, knowledge, and knowledge structures. By examining changes in knowledge structures and mental processes as the job skills develop, cognitive task analysis provides an understanding of how a task is learned and how to facilitate learning.

5. Guidelines for Conducting Cognitive Task Analysis. These guidelines define the procedures for accomplishing a comprehensive cognitive task analysis and preparing the cognitive task analysis deliverables.

   5.1 Identification of Key Job Tasks and Training Issues. The overall goals of the analysis are discussed. Job tasks or functions suitable for a cognitive task analysis are identified. Training issues or problems associated with the tasks are identified so they can be addressed in the analysis.

5.2 Visual Representation of the Knowledge Structure. The overall organization of experts' or good performers' knowledge about the task is presented in a visual format such as a network of linked concepts, a tree diagram, or a schema depicting interrelationships between knowledge.

5.3 Description of Cognitive Processes Underlying Performance. The key skills (e.g., long-range planning, projecting aircraft routes), knowledge, and learning and performance strategies that support effective task performance are described.

5.4 Identification of Differences Between Experts and Less-Experienced Personnel. Differences are described between experts and less-experienced personnel in their knowledge structures, skills, knowledge, and learning and performance strategies. The differences are discussed in terms of how individuals learn the task, how learning might be facilitated, and how expertise for the task develops over time.

5.5 Implications of Results for the Design Phase. The Final Cognitive Task Analysis Report discusses designing instruction so as to best facilitate progression from one proficiency level to the next. Areas covered include training structure, training sequence, and the selection of instructional setting, instructional strategies, and media delivery systems.

6. Discussion. Cognitive task analysis includes a wide variety of data collection and analysis methods, with each analyst modifying or combining methods to best fit the task to be analyzed. Additionally, because of the resource-intensive nature of cognitive task analysis, it may not always be possible to accomplish all of the analytic tasks outlined in the guidelines. For example, it may be desirable to limit the analysis only to experts, identifying only expert-typical knowledge structures, skills, and strategies. Or, the analysis may have the goal of examining only one aspect of expertise or job competence, such as effective learning and performance strategies. The Research Proposal should specify which analytic tasks will be completed.

7. Suggested References. The following references are suggested for more detailed information about systematic approaches to conducting cognitive task analysis, particularly within an ISD framework:

Beckschi, P. F., Lierman, B. C., Redding, R. E., & Ryder, J. M. (1991). Procedural guide for integrating cognitive methods into ISD task analysis. Special Report, Air Force Training Command.

Bonar, J., et al. (1986). Guide to Cognitive Task Analysis. Pittsburgh: Learning Research and Development Center, University of Pittsburgh.

Branson, R. K., & Grow, G. (1987). Instructional Systems Development. In R. Gagne (Ed.), Instructional Technology: Foundations. Hillsdale, NJ: Erlbaum.

7. Suggested References. (Continued)

Hoffman, R. R. (1987, Summer). The problem of extracting the knowledge of experts from the perspective of experimental psychology. AI Magazine, pp. 53-67.

Ryder, J. M., & Redding, R. E. (1991). Integrating cognitive task analysis into Instructional Systems Development (ISD). Submitted for publication. (Available from Human Technology, Inc.)

Ryder, J. M., Redding, R. E, & Beckschi, P. F. (1987). Training development for complex cognitive tasks. In Proceedings of the Human Factors Society - 31st Annual Meeting (pp. 1261-1265). Santa Monica, CA: Human Factors Society.

GUIDELINES FOR CONDUCTING COGNITIVE TASK ANALYSIS

1. PURPOSE

1.1 These guidelines describe the procedures and the deliverables for a cognitive task analysis conducted within the analysis phase of the ISD process. Cognitive task analysis is a systematic process for studying the cognitive processes and structures that support work performance. The analysis determines the knowledge structures, knowledge, skills, and strategies needed for high-level job performance, and identifies important differences between experts as compared with those having less experience.

1.2 The deliverables of a cognitive task analysis include:

a. Research Proposal. The research proposal explains how the specifications are to be met, by presenting a design for the research.

b. Interim Report (Optional). The interim report details the progress made toward meeting the specifications, and describes any proposed modifications to the research proposal. Because this deliverable is optional, it may be desirable for the interim report to discuss only selected items included in the guidelines. For instance, the report might only discuss modifications of the data collection and subject selection procedures based upon information obtained from pilot testing.

c. Final Cognitive Task Analysis Report. The final report presents the complete results from the implementation of the research proposal.

1.3 The task analysis research proposal, interim report, and final report present the following information:

a. Goals of the task analysis

b. Selection of tasks and issues studied

c. Subjects

d. Data collection methods

e. Data analysis methods

f. Results validation methods

g. Results of the task analysis

1.4 In presenting the results of the cognitive task analysis, the final report may include:

a. Visual representation of the knowledge structure

b. Description of cognitive processes underlying performance

- Skills
- Conceptual and procedural knowledge
- Learning and performance strategies

c. Identification of differences between experts and less-experienced personnel

- Differences in knowledge structures (Optional)
- Differences in skills
- Differences in conceptual and procedural knowledge
- Differences in learning and performance strategies

d. Implications of results for the design phase

- Training structure
- Training sequence
- Selection of instructional setting, media, and strategies

2. GUIDELINES FOR CONDUCTING A COGNITIVE TASK ANALYSIS

2.1 Goals of the Task Analysis. Identify the major goals of the analysis, describe the job task(s) and training problems that are the focus of the analysis, and provide justification for the selections. Justify the need for conducting a cognitive task analysis on the task(s) and problem(s) identified.

a. Identify major goals.

2.1 Goals of the Task Analysis. (Continued)

b. The analysis must focus on a set of questions, issues, or problems. Delineate the specific training problems, learning needs, or questions that the analysis addresses. This information may include the identification of:

- Long-term knowledge to be retained by the target population
- Time-sharing skills to be developed by the target population
- Effective cognitive-optimizing strategies
- Effective knowledge organization for the task
- Effective learning and performance strategies
- Methods for improving the transfer of skills
- Methods for developing better problem-solving skills

c. Provide evidence for the training problems discussed in Item b (above).

d. Select job tasks or functions to be analyzed.

e. Provide reasons for job task selections. Is the entire job being analyzed? If not, task components or functions should be carefully selected to include those that represent major training problems, are of critical importance to the job, involve a high degree of cognitive skills, and/or are particularly well-suited for cognitive task analysis techniques; for example:

- Critical tasks (criticality, difficulty)
- Job bottlenecks
- Tasks on which operators make frequent errors
- High workload tasks requiring attention-switching or division of attention between task components
- Tasks involving high performance skills (i.e., requiring massive amounts of practice to obtain proficiency)
- Tasks with a significant judgmental component involving problem-solving or decision-making

2.1 Goals of the Task Analysis. (Continued)

e. Provide reasons for job task selections. (Continued)

- Tasks requiring large amounts of knowledge to be assimilated during training
- Tasks that experts have considerable difficulty verbalizing or demonstrating through overt actions
- Complex tasks in which there may be considerable variability in how an individual performs the task, due to a number of cognitive strategies available

f. Provide evidence for the task characteristics discussed in Item e (above).

g. Include a description or review of what is already known about the nature of expertise in the job task, based on information obtained from:

- Technical manuals
- Operating procedures
- Interviews with subject-matter experts
- Observation
- Previous research
- Professional literature
- Occupational surveys
- Agency orders

2.2 Subjects. Describe the subjects of the analysis, covering the following points:

a. Ability or Experience Levels. Describe the range of ability or experience levels represented in the sample. Experts and novices or good and poor performers should be included. Ideally, novices, apprentices, sojourners, and several different types of experts (e.g., supervisors, best-rated experts, experts with less experience) would be included if differences between experts and novices are being investigated.

2.2 Subjects. (Continued)

b. Measurement and Selection. Are the subjects within each group truly representative of the group? Describe the definition of "expert." How is expertise for this task defined and measured? This description might specify:

- Years of experience
- Performance ratings by supervisors
- Proficiency or achievement test scores
- Peer nomination
- Time to complete task(s)

c. Sample Size. Is sample size for each subject group large enough to get a representative range of results and a representative picture of performance?

2.3 Data Collection Methods. Describe the methods used to collect data, covering the following points:

a. Selection of Methods. Describe which methods are used. Explain how each method selected addresses one or more of the issues/questions/training problems that are the focus of the analysis. Explain why the method is appropriate for the type of job task(s). If a relatively small sample size is used, ensure that the method is powerful and sensitive enough to reveal differences even in small samples.

Cognitive task analysis methods typically fall into one of four general categories:

- Protocol Analysis. This method involves having subjects think aloud while performing a task or while describing task performance. The verbalizations are then used to infer the individual's cognitive processing for the task.
- Psychological Scaling. This method involves having subjects make judgments through sorting, rating, or ranking task-relevant knowledge, or measuring subjects' recall, response times, output orders, and/or errors. The results are used to obtain proximity estimates from the subjects' judgments, rankings, sortings, or responses to stimuli in order to infer psychological structure (for example, how concepts relating to the task are organized in memory).

2.3 Data Collection Methods. (Continued)

a. Selection of Methods. (Continued)

- Performance Modeling. When using this method, simulations are constructed of a job or task, and a model of task performance is developed which is tested and refined by varying inputs, operator characteristics, or task characteristics to evaluate their effects upon simulated performance.

- Observation of Job Performance, and Interviewing. These traditional task analysis techniques are also used in cognitive task analysis. One modification of traditional observation is to induce modified task behavior, and then observe performance. Traditional interview techniques are often modified in order to elicit information about reasoning processes.

b. Reliability and Validity of Methods Selected. What is the reliability and validity of each method used? Discuss the selected methodology in terms of past research findings, and describe how validity and reliability are established in the current study:

- Conduct pilot testing on each data collection method and measurement instrument.

- Obtain intercoding reliability ratings.

- Obtain cross-validation from subject-matter experts.

- Revise procedures based on the above findings.

c. Controlled Experimental Design. Discuss the adequacy of the overall experimental design to ensure there are effective controls in place for accurate measurements and interpretation of results. Ensure the methodology conforms to sound scientific practice. Consider:

- Controlled conditions

- Internal validity

- Potential confounding variables

- Potential extraneous influences

- Demand characteristics

- Experimenter effects

2.3 Data Collection Methods. (Continued)

- Realism of stimuli, scenarios, and task simulations
- Clear and unambiguous instructions to subjects
- Random assignment of subjects to treatment conditions
- Adequate data collection and recording equipment (e.g., high-fidelity audio and video)

d. Convergent Methods and Measures. Discuss the adequacy of convergent methods. Are differing techniques used so as to provide cross-validation of the results obtained from the various data collection methods? Is there a representative sampling of problem types and subtasks (e.g., typical problems, tough problems, time-constrained problems, difficult subtasks, easy subtasks) in order to get at different aspects of task performance?

e. Measures and Experimental Treatments. Are the measures and comparisons well-defined?

- What different experimental treatments (conditions) are present? For example:
  - High-complexity versus low-complexity problems
  - High-difficulty versus low-difficulty problems
  - Complete versus partial information provided
  - Unlimited time versus limited time provided
- What group comparisons are made? For example:
  - Experts versus intermediates versus novices
- What measures are taken for use in the data analysis? For example:
  - Number of times a strategy is used
  - Number of times a particular knowledge category is used
  - Mean similarity ratings
  - Time to complete task

2.3 Data Collection Methods. (Continued)

f. Subsequent Iterations and Refinements. Discuss provisions for additional data collection subsequent to the initial data collection. How is the information gained during the early stages of data collection and analysis used to guide and fine-tune future task selection and analysis goals, and future data collection and analysis?

2.4 Data Analysis Methods. Discuss how the data are analyzed, covering the following points:

a. Coding. What coding scheme is used and what is the rationale for using it? How are reliability and validity established for the coding?

b. Data Analysis. What analysis is performed? Statistical analysis? Subjective content analysis? Model-building exercises? Provide the rationale for the data analysis method used—consider how it is appropriate, as related to:

- Data collection method used
- Statistical or other properties of the data (e.g., whether normal distribution, restricted range of data, subjects' rankings on a questionnaire, small sample size, etc.)
- Questions/issues of concern
- Type of output desired (e.g., whether a mental model, network diagram, sets of production rules, etc.)

2.5 Results Validation. Provide validation for the results obtained and for any models flowing from those results. Consult with multiple subject-matter experts in order to obtain validation for the models developed, the results obtained, and the interpretation of subjects' responses. The following should be discussed or considered:

a. Completeness. How complete are the models? What aspects of performance do they describe?

b. Significance. How important and useful are the models for understanding the job?

c. Generalizability. How representative are the results, and to what extent can the findings be generalized to other individuals, tasks, and situations?

2.5 Results Validation. (Continued)

d. Reasonableness. Do the results and models seem reasonable, based upon the experts' own experience, other results obtained, and what is already known about the job?

e. Predictability. Do the models allow one to predict performance once certain parameters are known?

f. Limitations of the Data. Discuss the results in terms of what information is provided, what remains unknown, and what is indicated for future research. Discuss applicable caveats and cautions in interpreting and generalizing the findings. Discuss the overall reliability and validity of the findings and the range of application of the models.

g. Subsequent Iterations/Refinements. Discuss whether there is a need for model refinement or results verification through further data collection, analysis, or validation efforts.

2.6 Results. Discuss the results by providing an explicit model of the knowledge structure, skills, knowledge, and strategies underlying expertise for the task(s). The following should be discussed or considered:

a. What do the results reveal overall about the nature of expertise in the task? Describe the results in terms of:

- Effective mental models for the task
- Types of skills required for competent performance
- Effective cognitive-optimizing strategies
- Effective learning and performance strategies
- Knowledge, skills, and learning styles of experts

b. Provide outputs from the data analysis, including a visual representation(s) of the knowledge structure. For example, present results in terms of:

- Network scaling showing the interrelationship among items through a series of linked nodes. (See an example in Figure 1.)
- Tree diagram

2.6 Results. (Continued)

- Mental model (See an example in Figure 2.)
- Schema

b. Provide outputs from the data analysis, including a visual representation(s) of the knowledge structure. (Continued)

- Hierarchical cluster depiction (showing groupings of related items within a hierarchy)
- Multidimensional scaling depiction (showing how items interrelate along key psychological dimensions or axes)
- Systematic grammar networks (networks showing how knowledge elements are categorized and the levels at which category distinctions are made)
- Repertory grid (grid showing the important psychological distinctions between concepts)

c. Discuss the conceptual and procedural knowledge needed for the task as a whole, including key domain concepts and how they interrelate, and important task components or subgoals.

d. Identify strategies, heuristics, algorithms, or aids used for learning or in job performance, including:

- Production rules
- IF....THEN rules
- Heuristics
- GOMS (Goals, Operators, Means, Selection Rules)
- Decision trees
- Rules of thumb
- Effective job aids

e. If automaticity or time-sharing skills are one focus of the analysis, identify task components that are consistent. Note that consistent task components often do not correspond to task elements and activities.

2.6 Results. (Continued)

f. Discuss the differences between the subject groups, including:

- Similarities between groups
- Differences between groups, and reasons for the differences
- Learning progression and skill acquisition
- Learner characteristics

g. Discuss the interrelationships among results obtained and the models developed. For example, how does the expert-typical knowledge structure support the learning or execution of performance strategies? How does it support problem-solving?

2.7 Implications of Results for the Design Phase. Discuss what the results and the models mean for training design, covering the following points:

a. Recommended Training Structure. Discuss the content and organization of instructional material with reference to the knowledge organization. Discuss how best to present instructional material initially and how to facilitate progression to effective knowledge representations:

- Using the expert model as an organizational framework both for learning and for job performance
- Using the expert model to diagnose and remedy novice errors
- Improving organization to support problem-solving
- Improving understanding of interrelationships

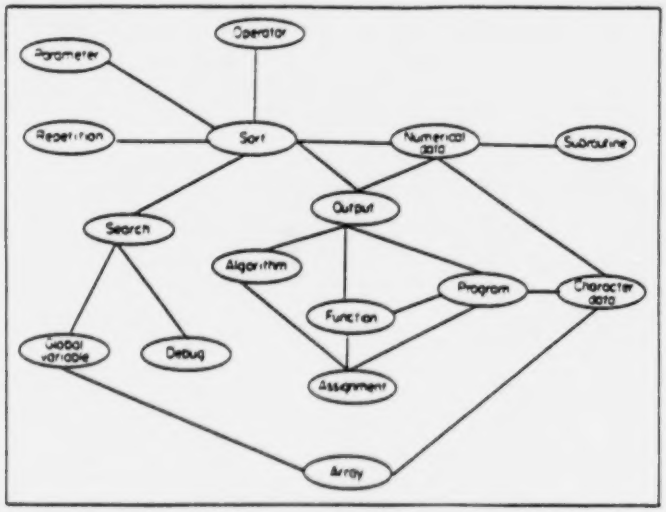
2.7 Implications of Results for the Design Phase. (Continued)

b. Recommended Training Sequence. Discuss sequencing of instruction according to skill, knowledge, and knowledge structure progressions. The discussion should cover:

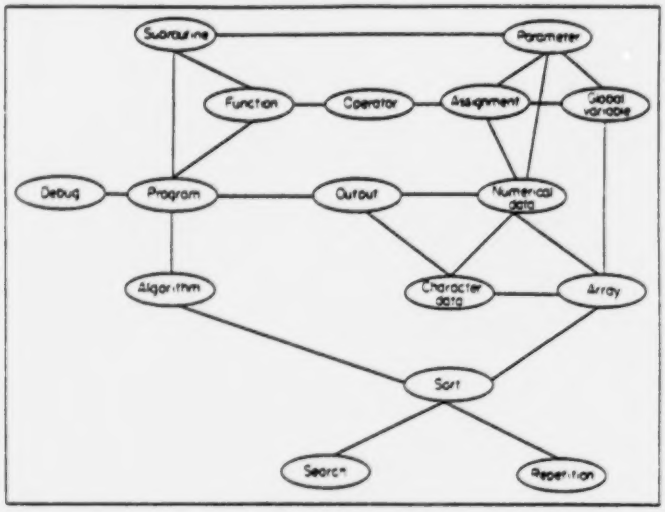
- Job tasks
- Task subgoals
- Knowledge domains
- Mental model components
- Cognitive skills (e.g., teaching attention allocation before advanced problem-solving)
- Strategies (e.g., simpler strategies before more complex)

c. Recommended Instructional Setting, Media, and Strategies. Discuss the conditions that best facilitate learning according to the types of knowledge, skills, and knowledge structures underlying expertise and skill acquisition. For example:

- Types of learning methods and media
- Necessity of simulators for cognitive skill acquisition and practice
- Use of mnemonics and organizational aids to facilitate memorization
- Need to provide model-building learning activities to facilitate mental model development
- Need to provide different training modes to accommodate individual differences in learning styles



Network representation of the average cognitive structure of naive programmers



Network representation of the average cognitive structure of expert programmers

FIGURE 1. EXAMPLES OF NETWORK SCALING (COOKE & MCDONALD, 1987)

From: Cooke, N. M., & McDonald, J. E. (1987). The application of psychological scaling techniques to knowledge elicitation for knowledge-based systems. International Journal of Man-Machine Studies, 26, 533-550.

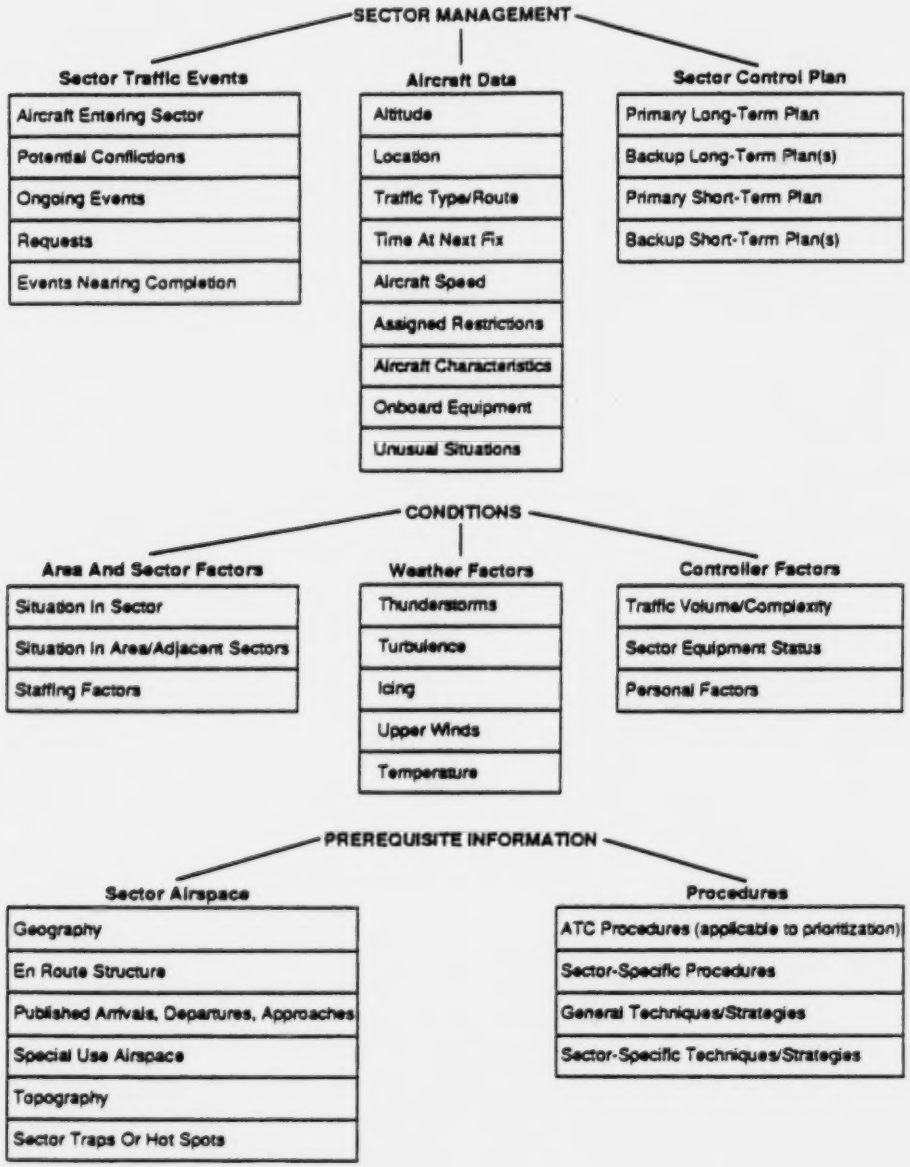


FIGURE 2. EXAMPLE OF AN EXPERT MENTAL MODEL (REDDING ET AL., 1991)

From: Redding, R. E., Cannon, J. R., Lierman, B. C., Ryder, J. M., Purcell, J. A., & Seamster, T. L. (1991). The analysis of expert performance in the redesign of the en route air traffic control curriculum. Proceedings of the Human Factors Society - 35th Annual Meeting (pp. 1403-1407). Santa Monica, CA: Human Factors Society.